FIRE PROGRAM ANALYSIS (FPA) PREPAREDNESS MODULE

With Focus on

OPTIMAL DEPLOYMENT for INITIAL ATTACK

(SUMMARY REPORT OF PRELIMINARY PROGRESS)
Working Paper

Douglas B. Rideout, Andy Kirsch and Dan Keller

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INTRODUCTION

This preliminary report summarizes substantial progress that we have made since we began this project in August, 2002. Our work is intended to support the development of the new FPA preparedness module. It is also our intent that documentation of progress will aid in informing the core team of our thinking on the economic structure of the new model.

This report of progress reflects valuable interactions and discussions with each member of the FPA core team. While we discuss "our formulation" in the sections below, in the bigger picture this progress reflects many focused and constructive interactions with each member of the FPA core team. We believe that the core team is poised to make important history in the development of the Phase I and Phase II efforts. The accomplishments of Phase I may serve as an example of how a major federal government program can powerfully and directly address new standards of public accountability and integrate across separate federal agencies with an economically sound and focused solution designed and constructed to the highest standard. This effort has the potential to make significant contributions to many fields including: public administration, management of non-monetized resources, public finance, operations research, and resource economics.

OPTIMAL DEPLOYMENT AND BUDGETING MODEL

We have made great progress on the mathematical formulation and mathematical programming of a prototype optimal deployment model for use in the FPA initial attack system. We can summarize our general findings here.

- This report contains an overall system vision developed by the FPA core team presented here as context for the optimization formulation.
- We have completed a mathematical formulation of the core of an Integer Program (IP) for use in FPA phase one.
- Our formulation is a strong demonstration that the mathematical programming approach, using an IP, is appropriate and it is feasible. This is a major finding that bodes well for the potential success of the Phase I project in terms of completing a product that directly addresses the concerns of OMB in a credible way within a reasonable time frame. Our formulation can serve as a basis for commercial contracting requests and specifications.
- Our formulation addresses the initial attack problem in the context previously developed and described with the team in meetings in Boise.
- Our formulation represents a major advancement in that it includes simultaneous deployment to multiple fires—a condition not previously available.
- We have carefully considered interests and concerns expressed by team members in the formulation of the model so that we are clear as to the implications and mechanics of including them. Our core formulation seems to be robust in the sense that it handles "issues" in budgets well within its structure. It is important, even crucial, to remember that this is a new approach that is operationally different and much more potent than any currently in use. It will ultimately require a different "mind set" than we have grown accustomed to for decades.

- Our formulation is a major improvement over the IIAA portion of NFMAS. A few of these improvements include:
    1) serious economic errors are corrected,
    2) relationships between decision variables and their affect on outcomes are clearly specified and corrected,
    3) the non-monetized measure of effectiveness (the quality acre protected QAP) better applies to the full spectrum of agency missions and to the direction that all agencies are taking,
    4) the mechanics of computing a solution are "assigned" to the computer so that the burden of searching for the result is lifted from the operator(s).
    5) The formulation will directly and soundly address the OMB concern of specifying what can be accomplished for a given budget/cost level with the utmost integrity.
- The **scope** of the model is focused on the initial attack problem. Our formulation optimally deploys fire fighting resources so as to maximize the quality acre protected for a specified budget/cost in a way that will generate budgets for the planning unit that can be accumulated nationally for program analysis and budget requests. The scope is strategic in this regard as opposed to tactical. Therefore the formulation and related model will not appropriately address the tactics of deployment for a particular fire event. Similarly, because the scope is limited to initial attack, the formulation and the related model is not appropriately used as a land management planning tool. It can, however, through its weighting system reflect planning considerations such goals or objectives.
- **Design of a non-monetized weighting system is required**. We recommend that the core team consider forming a sub-group or task force to complete an framework for generating and applying weights. **It is important to remember that weighting is nothing new. Current models, including IIAA use weighting**. The only substantive difference at this point is that the weights used here would be non-monetized.

While we have completed an initial formulation of the core deployment problem, we will continue to address enhancements or improvements throughout the project. We recognize that there is much more that needs to be accomplished in terms of testing, documentation, explanation—to mention a few items.

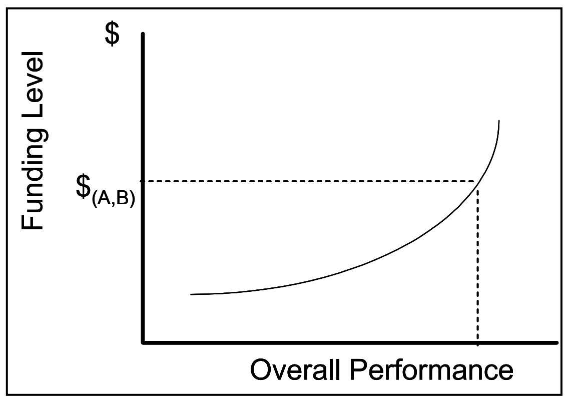
Structure of the Model

The Fire Program Analysis (FPA) Preparedness Module will determine effectiveness measures for a range of wildfire preparedness budget and suppression costs.

In the context of FPA Preparedness analysis, "effectiveness" will be measured as the total weighted acres protected by fire management unit (FMU) and fire intensity level (FIL) within each FMU. This can be thought of as the quality acre protected (QAP).

Weights associated with each FMU and FIL will represent the relative importance of protecting acres within the FMU by FIL. For example, it may be more important to suppress high intensity fires than low intensity fires. It may also be more important to suppress fires within the wildland urban interface (WUI) than to suppress fires in the general forest backcountry. Weights will relate to specific fire management objectives and natural resource management objectives some of which may be non-monetized.

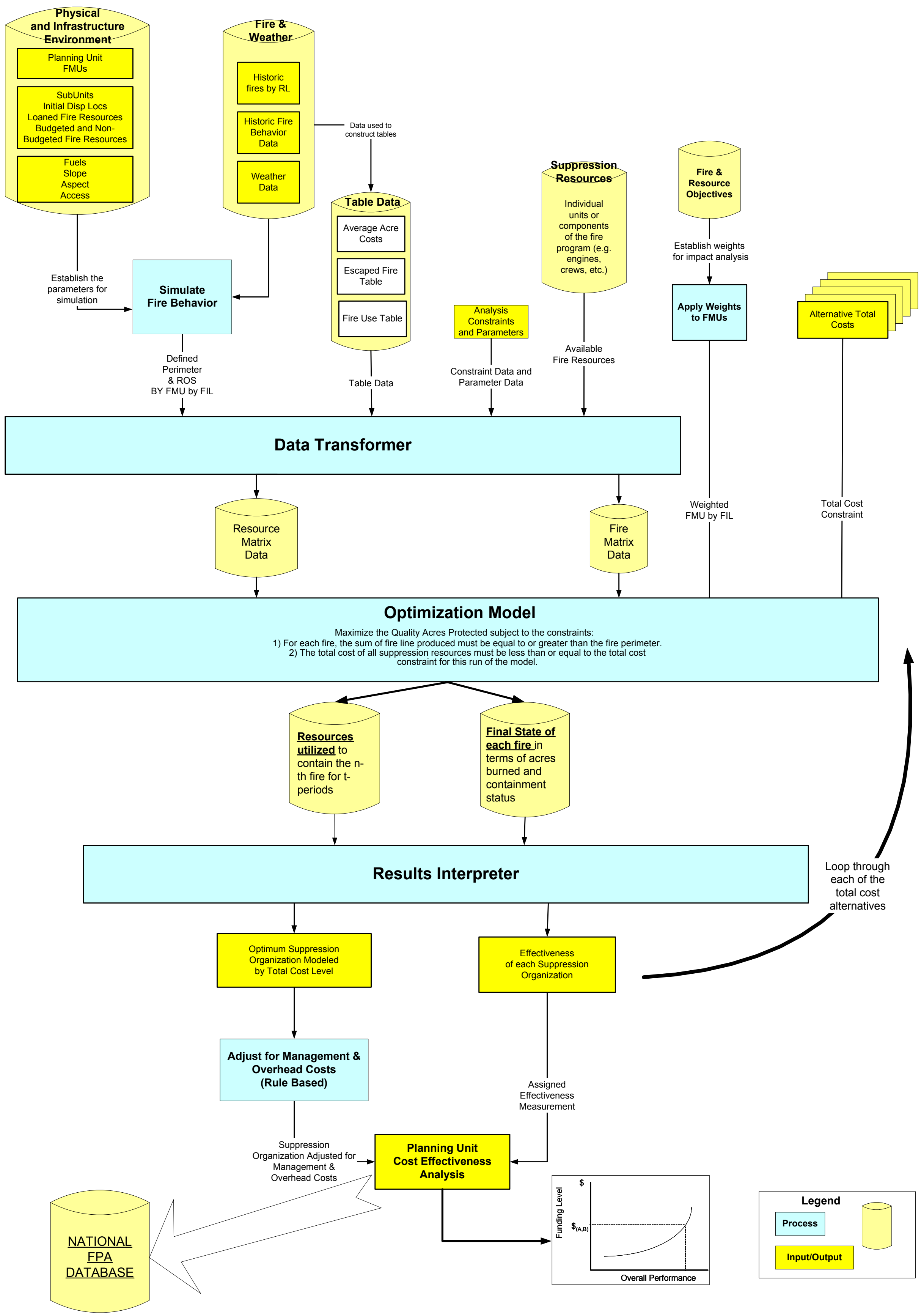
The objective function of the FPA preparedness analysis will maximize sum of quality acres protected by FMU and FIL across a range of total costs. Total cost is the sum of the preparedness budget and suppression cost.



The results will be displayed as a tradeoff curve comparing effectiveness to a range of total cost.

This will allow decision makers to evaluate the tradeoff of initial attack preparedness program levels to effectiveness to make informed budget decisions.

The overall FPA system vision is represented in the schematic below with associated definitions.



Physical and Infrastructure Environment
Planning Unit FMUs
SubUnits Initial Disp Locs Loaned Fire Resources Budgeted and Non-Budgeted Fire Resources
Fuels Slope Aspect Access
Fire & Weather
Historic fires by RL
Historic Fire Behavior Data
Weather Data
Data used to construct tables
Table Data
Average Acre Costs
Escaped Fire Table
Fire Use Table
Suppression Resources
Individual units or components of the fire program (e.g. engines, crews, etc.)
Fire & Resource Objectives
Establish weights for impact analysis
Apply Weights to FMUs
Alternative Total Costs
Establish the parameters for simulation
Simulate Fire Behavior
Analysis Constraints and Parameters
Defined Perimeter & ROS BY FMU by FIL
Table Data
Constraint Data and Parameter Data
Available Fire Resources
Data Transformer
Resource Matrix Data
Fire Matrix Data
Weighted FMU by FIL
Total Cost Constraint
Optimization Model
Maximize the Quality Acres Protected subject to the constraints:
1) For each fire, the sum of fire line produced must be equal to or greater than the fire perimeter.
2) The total cost of all suppression resources must be less than or equal to the total cost constraint for this run of the model.
Resources utilized to contain the n-th fire for t-periods
Final State of each fire in terms of acres burned and containment status
Results Interpreter
Loop through each of the total cost alternatives
Optimum Suppression Organization Modeled by Total Cost Level
Effectiveness of each Suppression Organization
Adjust for Management & Overhead Costs (Rule Based)
Assigned Effectiveness Measurement
Suppression Organization Adjusted for Management & Overhead Costs
Planning Unit Cost Effectiveness Analysis
NATIONAL FPA DATABASE
$
$(A,B)
Funding Level
Overall Performance
Legend
Process
Input/Output

FPA System Preparedness Model Vision Diagram Descriptions	
Diagram Reference	**Definition/Description**
Access	The mode of transportation (walk-in, drive-in, fly-in) required to get to a Fire Management Unit.
Adjust for Management and Overhead Costs (Rule Based)	The process of using pre-defined rules to adjust suppression organizations to include overhead and management costs.
Alternative Total Costs	A range of dollar values over which the analysis will be run, expressed as the lower limit, upper limit and interval.
Analysis Constraints and Parameters	The analysis constraints are the restrictions that are applied to the planning analysis, such as no mechanized equipment in wilderness areas. The analysis parameters are the miscellaneous base data that is needed by the analysis, such as length of time period, number of periods until a fire is considered
Apply a Weight for each FMU by FIL based on Objective(s)	The process of setting a weight for each FMU by FIL, based on management objectives. Weights reflect the relative importance of protecting acres in the FMU from wildfire.
Aspect	The direction a slope faces, in relation to the points of the compass.
Average Acre Cost (AAC)	The emergency suppression costs for both escaped and non-escaped fires based upon the final contained fire size. For non-escaped fires, AAC is used to represent direct fire related costs incurred after containment. For escaped fires, AAC is the sole determinant of the total suppression cost.
Budgeted Fire Resources	A category of fire protection forces available for initial attack that must be included in the budget for each agency within the fire planning unit.
Data Transformer	Procedures that calculate data needed by the optimization model based on basic environmental, infrastructure and suppression resource data. Technically referred to as the “Optimization Matrix Generator”.
Effectiveness for each Initial Attack Organization	The measure of effectiveness (Quality Acres Protected) for each initial attack organization at a single associated total cost level.

FPA System Preparedness Model Vision Diagram Descriptions	
Diagram Reference	**Definition/Description**
Escaped Fire Table (EFT)	A table of the final estimated size of fires that are not contained by the simulation model (exceeded time or size constraints). The EFT is developed from historical large fire data for the Fire Planning Unit. Sizes may be defined for each FMU and each Fire Intensity Level.
Fire and Resource Objectives	Planned results to be applied to accomplish a fire management goal (e.g., to reduce the impact caused by unwanted wildland fire by x% over y years). An objective creates a standard that can be measured and evaluated.
Fire Intensity Level (FIL)	A measure of fire behavior based on flame length.
Fire Management Unit (FMU)	An FMU is any land management area definable by objectives, management constraints, topographic features, access, values to be protected, political boundaries, fuel types, major fire regime groups, and so on, that set it apart from the management characteristics of an adjacent FMU. The FMUs may have dominant management objectives and pre-selected strategies assigned to accomplish these objectives. The development of FMUs should avoid redundancy. Each FMU should be unique as evidenced by management strategies, objectives and attributes.
Fire Matrix	Attributes of each fire in terms of cumulative perimeter and area by time period as well as the objective function weight by time period.
Fire Planning Unit (FPU)	The geographic scope of the landscape defined for the fire management analysis. Fire Planning Units may relate to a single administrative unit, a sub-unit, or any combination of units and sub-units. Fire Planning Units are scalable, and may be contiguous or noncontiguous. Fire Planning Units are not predefined by the Agency administrative unit boundaries, and may relate to one or more agencies. They may be described spatially. A Fire Planning Unit consists of one or more Fire Management Units.
Fire Planning Unit Cost Effectiveness Analysis	The aggregation of all the effectiveness measures across all total cost levels.
Fire State	The results of the optimization model in terms of the final size of each fire and whether the fire was contained or not.

FPA System Preparedness Model Vision Diagram Descriptions	
Diagram Reference	**Definition/Description**
Fire Use Table	An unplanned but desirable fire (ignition), with no attack necessary. There is still a cost, but a different mix of resources is required.
Fuels	All dead and living material that will burn.
Historic Fire Behavior Data (FBD)	A table of numbers of fires and 50^{th} and 90^{th} percentile rates of spread for each Fire Intensity Level. It is used in IIAA in the simulation of fire occurrence and behavior. The FBD is developed from historic fire occurrence and fire weather data for each Fire Management Unit.
Historical Fire Table (HFT)	The tabulation of historical numbers of fires and rates of spread by size and intensity for the Fire Planning Unit.
Initial Dispatch Location	The designated headquarters, station, or point representing a more generalized location that is used as the dispatch point for initial attack resources, and from which travel distances to FMUs are measured.
Loaned Fire Resources	A category of fire protection forces available for initial attack that are not part of the Fire Planning Unit organization. The agencies that provide these resources are often referred to as cooperators.
National Shared Database	The FPA database that contains the analysis results for all planning units by agency by budget year. The database is used to make budget allocation decisions at the national level.
Non-budgeted Fire Resource	A category of fire protection forces available for initial attack that are not included in the budget for each agency within the fire planning unit.
Optimization Model	Maximizes effectiveness in terms of Quality Acres Protected (QAP) subject to total cost constraints and fire containment constraints.
Optimum Initial Attack Organization modeled by Total Cost Level	The initial attack organization that will maximize effectiveness at the assigned total cost.
Physical and Infrastructure Environment	The physical characteristics of the Fire Planning Unit; a description of existing conditions.
Rate of Spread (ROS)	The fire spread rate in chains per hour for up to six Fire Intensity Levels. (The number of FILs that any set of fire behavior data will have is determined by the fuel model and the weather used in the calculation.)

FPA System Preparedness Model Vision Diagram Descriptions	
Diagram Reference	**Definition/Description**
Resource Matrix	Attributes of each resource associated with each fire in terms of cumulative production rate (expressed in total chains), fixed cost, and variable cost by time period.
Resources Utilized	The results of the optimization model in terms of the final size of each fire and whether the fire was contained or not.
Results Interpreter	Calculates relevant information based on the results of the optimization model (Resources Utilized and Fire State) and basic data inputs.
Simulate Fire Behavior	The process of calculating the Rate of Spread (ROS) and FIL by time period for a fire within an FMU based on historic fire data (fuel, weather, topography).
Slope	The natural incline of the ground, measured in percent of rise over run. A factor used to determine ROS and may be a limiting factor for deploying mechanized equipment.
Sub-Unit	A portion of an administrative unit, such as a Ranger District, of the Fire Planning Unit. Sub-units are optional, and can be used for accounting purposes; they are not used in the analysis itself.
Suppression Resources	The individual units or components of the fire program (engines, crews, air tankers, administration, fire management officers, etc.) that are available to the initial attack model, together with their production rates, speeds, unit mission costs, and other fire-fighting characteristics. Suppression resources are categorized by budgeted, non-budgeted and loaned.
Total Cost Constraint	A fixed dollar amount that represents the upper limit of total cost allowed for a given optimization run. A series of optimizations will be run over the range of alternative total costs.
Weather Data	Archived weather observations that are input to the fire behavior simulator. Weather records are typically extracted from the National Interagency Fire Management Information Database (NIFMID). Fire records are agency-specific, and are retrieved for use according to local agency guidelines. Weather data, together with algorithms from the National Fire Danger Rating System (NFDRS) are utilized to calculate fuel moistures and fire behavior indices.

While there is much more clarification to be made of the FPA system vision, we focus here on the optimization formulation.

Optimization Model

The FPA preparedness model will utilize a linear optimization approach (integer programming) to establish the effectiveness frontier of quality acres protected. The integer program will maximize quality acres protected for a given cost level. The optimization model will then be run iteratively across a range of total cost constraints. The range of total costs will be determined by the minimum and maximum cost levels to be analyzed. The budgeted portion of total cost will also be calculated.

The integer program will model containment of a set of representative wildfires for each FIL in each FMU. Containment is achieved if the sum of the fire line constructed exceeds the fire perimeter in any time period for a given total cost. Each type of suppression resource has an associated fire line production rate, preparedness cost and utilization cost. The integer program will deploy fire fighting resources to attempt to construct fireline so as to maximize the firefighting effectiveness of a given total cost.
If the model is unable to contain a fire within its cost allotment, then the fire is assumed to have escaped initial attack and it's size defaults to the "escaped fire size." The escaped fire size and cost is estimated from statistical analysis of historical fire and weather data.

The optimization model will

(1) Maximize the sum of the weighted acres protected by FMU and FIL

Subject to:

(2) Fire containment constraints which determine the final fire size.

(3) Total cost constraint.

Fire suppression resources will include attributes that may limit their use in specific FMUs. E.g., fire engines and dozers may not be used in wilderness FMUs.

Results

Each run of the optimization model determines a single point on the effectiveness frontier. Each point represents a combination of total cost and the most effectiveness that it can attain as measured by quality acres protected. By iteratively running the optimization model across cost levels, the entire effectiveness frontier will be mapped.

Mapping the effectiveness frontier will allow budget planners to determine the preparedness staffing needs, the associated effectiveness and the acres that would be expected to burn by FMU and FIL for a given budget level, assuming the weather and climate data that were used as inputs remain constant.

Additionally, a selected set of model data and results will populate the **national FPA database** for all the planning units in the nation. This will allow national budget planners will be able to assess tradeoffs between planning units nationwide. This should allow global optimization of preparedness budgets.

DATE: 01-03-2002

FPA Model with Multiple Fires

Assumptions/Notes

1) Fires do not cross FMU boundaries and the resources don't compete- unless they are ground resources, in which case they would compete for simultaneous fires. Aerial resources do not compete for any fire, simultaneous or otherwise.

2) Fires burn until the end of the time period, in this case measured in hours and resources are used for the full hour even in the containment period.

3) Arrival times are accounted for in the production rates. i.e. if it takes resource (r) 2 hours to arrive, $PR_{ir1} = 0$ and $PR_{ir2} = 0$. Fractions of an hour can also be handled. By adjusting the production rates in the same manner, one can account for decrease in production caused by fatigue or refill times.

4) The exact deployment time is not relevant to containment- just the total production of each resource. The resource that was used the longest was sent in the first time period.

5) In the I.P. all resources are deployed based upon their cost of regular time and overtime. Hazard pay is always present. A separate routine can be run using the I.P output to re-calculate the overtime and apportion it between budgeted and non-budgeted costs.

6) Escaped fires are handled as an external table. This is necessary to keep cost as an input to the I.P. The Dual problem is to Minimize cost for a fixed or input level of effectiveness. In the dual, escaped fire cost would be solved for by the I.P.

7) Example resource input table for the third fire, Budgeted resource 2 over time period (t),

BR3,2,t $=B_{irt}$				
BR_{irt}				
Duration	1	2	3	4
Production	0	5	10	14
Hourly Cost	10	20	30	40
Fixed Cost	15	15	15	15

Example Fire input table for the first fire over time period (t).

F1,t $= F_{it}$						
F_{it}						
Duration	0	1	2	3	4	5
Perim	2	4	5	9	15	40
Acres	.25	1	1.5	5.1	14.3	101
Weights	2	2	2	2	2	5

Decision Variables

BR_{irt} = Binary(0,1) = 1 if the (rth) Budgeted resource is used for a total of (t) time periods on the (i)th fire (i.e. the resources that belongs to the planning unit.) =0 if the resource was never used.

LR_{irt} = Binary(0,1) = 1 if the (rth) Loaned resource is used for a total of (t) time periods on the (i)th fire (i.e. resources borrowed from neighboring units or other agencies, but still budgeted). =0 if the resource was never used.

NBR_{irt} = Binary(0,1) = 1 if the (rth) Non-Budgeted resource is used for a total of (t) time periods on the (i)th fire. =0 if the resource was never used.

F_{it} = Binary (0,1) = 1 if the (i)th fire burns for a total of (t) time periods

S_i = slack (the difference between the (i)th fire's perimeter and the line produced). If S_i is >0 then the fire has escaped.

EF_i = Binary(0,1) = 1 if the (i)th fire is an escaped fire.

USE_BR_r = Binary(0,1) = 1 if the (r)th budgeted resource is used at all. This variable is used in the Fixed cost calculation.

USE_LR_r = Binary(0,1) = 1 if the (r)th loaned resource is used at all. This variable is used in the Fixed cost calculation.

USE_NBR_r = Binary(0,1) = 1 if the (r)th non-budgeted resource is used at all. This variable is used in the Fixed cost calculation.

Input – Exogenous to I.P.

RD_t = Resource Duration. The value of total elapsed integer time from 1 to T, where T is the number of duration periods modeled.
FD_t = Fire Duration. The value of total elapsed integer time from 0 to XFT (including 0).
XFT = The escaped fire time(T+1) - defined as the number of time periods in the model, T, plus 1.
$FXBR_r$ = total fixed cost accrued for budgeted resource (r)
$FXLR_r$ = total fixed cost accrued for loaned resource (r)
$FXNBR_r$ = fixed cost for non-budgeted resource (r)
HBR_{rt} = total hourly cost accrued for budgeted resource (r) through the end of period (t)
HLR_{rt} = total hourly cost accrued for loaned resource (r) through the end of period (t) **$HNBR_{rt}$** = total hourly cost accrued for non-budgeted resource (r) through the end of period (t)
$PRBR_{irt}$ = total (cumulative) line produced by budgeted resource (r) through the end of period (t) in during the (i)th fire
$PRLR_{irt}$ = total (cumulative) line produced by loaned resource (r) through the end of period (t) in during the (i)th fire
$PRNBR_{irt}$ = total (cumulative) line produced by non-budgeted resource (r) through the end of period (t) in during the (i)th fire
W_{it} = Weight of the (i)th fire at the end of time (t).
P_{it} = Total fire perimeter for the (i)th fire through the end of period (t)
A_{it} = Total area burned for the (i)th fire through the end of period (t). Calculated from P_{it}. (using a conversion of perimeter to area for a fire shape of choice- 2:1 ellipse for example.)
R = index for all of the different types of resources
TC = the total cost of suppression
T = index for the time periods
I = index for the number of fires
E_0 = The amount of weighted Acres that would have burned if no suppression action was taken. Sum of escaped fire table values.
MF= the number of fires considered simultaneous/multiple fires.

Objective Function

MAX QAP = E_0- QAB

so,

MAX QAP = $E_0 - \left\{ \sum_{i=1}^{I} \sum_{t=0}^{T} \{(W_{it} * F_{it} * A_{it})\} \right\}$

Constraints

1) $\forall i, \forall r \left\{ \sum_{t=0}^{XFT} F_{it} * FD_t \geq \sum_{t=1}^{T} BR_{irt} * RD_t \right\}$

$\forall i, \forall r \left\{ \sum_{t=0}^{XFT} F_{it} * FD_t \geq \sum_{t=1}^{T} LR_{irt} * RD_t \right\}$

$\forall i, \forall r \left\{ \sum_{t=0}^{XFT} F_{it} * FD_t \geq \sum_{t=1}^{T} NBR_{irt} * RD_t \right\}$

1a) $\forall i \left\{ \sum_{t=0}^{XFT} F_{it} * FD_t \geq EF_i * XFT \right\}$

2) $\forall i \left\{ \sum_{t=1}^{T} \sum_{r=1}^{R} (BR_{irt} * PR_{irt}) + \sum_{t=1}^{T} \sum_{r=1}^{R} (NBR_{irt} * PR_{irt}) + \sum_{t=0}^{T} \sum_{r=1}^{R} (LR_{irt} * PR_{irt}) + S_i \geq \sum_{t=0}^{XFT} F_{it} * P_{it} \right\}$

3)
$$\sum_{i=1}^{I} \sum_{r=1}^{R} \sum_{t=1}^{T} \{BR_{irt} * HBR_{rt} + LR_{irt} * HLR_{rt} + NBR_{irt} * HNBR_{rt}\} + \sum_{r=1}^{R} USE\_BR_r * FXBR_r + \sum_{r=1}^{R} USE\_LR_r * FXLR_r + \sum_{r=1}^{R} USE\_NBR_r * FXNBR_r \leq TC$$

4) $\forall i, \forall r \left\{ \sum_{t=1}^{T} BR_{irt} = 1 \right\}$ $\forall i, \forall r \left\{ \sum_{t=1}^{T} NBR_{irt} = 1 \right\}$

$\forall i, \forall r \left\{ \sum_{t=1}^{T} LR_{irt} = 1 \right\}$ $\forall i \left\{ \sum_{t=0}^{XFT} F_{it} = 1 \right\}$

5) $\forall i \{100 * S_i \geq EF_i\}$

$\forall i \{100 * EF_i \geq S_i\}$

6) $$\forall r\left\{100 * \sum_{i=1}^{I}\sum_{t=1}^{T} BR_{irt} * RD_t \geq USE\_BR_r\right\}$$

$$\forall r\left\{100 * USE\_BR_r \geq \sum_{i=1}^{I}\sum_{t=1}^{T} BR_{irt} * RD_t\right\}$$

7) $$\forall r\left\{100 * \sum_{i=1}^{I}\sum_{t=1}^{T} LR_{irt} * RD_t \geq USE\_LR_r\right\}$$

$$\forall r\left\{100 * USE\_LR_r \geq \sum_{i=1}^{I}\sum_{t=1}^{T} LR_{irt} * RD_t\right\}$$

8) $$\forall r\left\{100 * \sum_{i=1}^{I}\sum_{t=1}^{T} NBR_{irt} * RD_t \geq USE\_NBR_r\right\}$$

$$\forall r\left\{100 * USE\_NBR_r \geq \sum_{i=1}^{I}\sum_{t=1}^{T} NBR_{irt} * RD_t\right\}$$

9) $$\forall r\left\{\sum_{i=1}^{MF}\ \sum_{t=1}^{T} BR_{irt} <= 1\right\}$$

$$\forall r\left\{\sum_{i=1}^{MF}\ \sum_{t=1}^{T} LR_{irt} <= 1\right\}$$

Objective function: Maximize quality acres protected.
Where E_0 denotes the quality acres burned with no deployment. E_0 is used to scale effectiveness (E) for comparisons of effectiveness frontiers across planning units.

1) The fire burns at least as long as the **longest duration** of any resource. Only one of these constraints will be binding for each fire in each FMU. The rest will be redundant.

1a) If there is an **escaped fire**, i.e. EF_{mi}=1 then the duration for the fire is the equal to the escaped fire time(XFT = the number of time periods in the model plus one.) The fire is then given the escaped fire acreage from the input table.

2) **Containment** constraint: Line production must be greater than or equal to the fire perimeter.

3) **Total Cost** constraint: Sum of the fixed costs plus the sum of the hourly costs must be less than the total cost

4) Only **one use** per resource. For example, the choice will be BR_{ir0} =1 if the resource (r) is never used. Note: Since resources don't compete it is possible for example to have BR_{111}=1 AND BR_{211}=1.

5) This set of constraints forces the binary variable EF_i =1 if there is any slack in fireline production.

6) This set of constraints forces the binary variable USE_BR_r =1 if the budgeted resource (r) is used on any fire.

7) This set of constraints forces the binary variable USE_LR_r =1 if the budgeted resource (r) is used on any fire.

8) This set of constraints forces the binary variable USE_NBR_r =1 if the budgeted resource (r) is used on any fire.

9) This is the **Multiple Fire** scenario. This set of constraints limits the ground resources (in this case budgeted and loaned) to only one fire. Here, the multiple fires are fires 1 through MF. For example, if MF=2 then fires 1 and 2 are simultaneous fires. The of the fires, 2 through I are regular fires with where the resources don't compete. If there were another set of fires that were simultaneous, another set of constraints similar to 9) would be created.

RESPONSE TO REQUIREMENTS ANALYSIS LOG and Milestone Review

I was also assigned items I the Requirements Analysis Question Log (Page 19, Version: 2, Release Date: 1/7/2003 Prepared by commonthread incorporated) as posted on the FPA web site. I have prepared the following responses.

Effectiveness (how defined?).

Effectiveness is defined as the quality acre protected (QAP) by deployment of fire fighting resources. The QAP is defined by identifying acres protected by fire intensity level within an FMU. Acres in each FMU are assigned a weight by FIL. It is important to the success of the process that the definition of effectiveness be straightforward and operationally viable. Effectiveness, or the QAP is calculated as the fire impact with no initial attack minus the impact of acres burned from unwanted and unplanned wildfires. Effectiveness replaces NVC, market and non-market valuation approaches.

This question also contains ancillary questions regarding objectives and budgets. Regarding objectives, it is crucial to remember that the initial attack module is intended to provide an economically sound approach to attacking unplanned and unwanted fires in the most effective way for a fixed cost. The cost is input (ala Marcus Peacock) and the model maximizes the QAP. This also improves upon the formulation of budgeting information. In particular, it directly addresses the crucial issue of "**what do we get for a given budget**." This defines important attributes of the **scope** of the FPA version one effort. Given this scope, it is also important to continue to recognize that this resource deployment and budgeting model is not a land management planning model. It does, however, directly link to planning objectives through the assignment of weights. The weighting system reflects the relative importance of protecting certain acres at certain fire intensities. Therefore, it is equally important that the model address planning objectives through the weighting process and not through additional constraints. Such constraints will impugn the integrity of the model and the system in potentially serious ways. At a minimum, they will conflict with direction from OMB by defining the outcome and then solving for the budget.

To better address goals or objectives, Andy and I have included the ability to assign weights within an FMU and by FIL on an hourly basis. This will enable the user to address concepts of **fire use** or herding, or to say something like "its ok for a fire to burn a certain no of acres, but it will become important to be more aggressive in the attack after a certain size." This is a potentially powerful improvement over assigning a weight for the entire FMU and will better address concerns related to goals. We are also aware that changing weights by the hour may be more than you really want to get into. Nevertheless, we have included hourly weighting in our core formulation and use it to address the escaped fire situation.

How are cost effectiveness and least damage defined? How is meeting out objective defined?

Cost effectiveness, in this context means maximizing the QAP at a specified cost. The cost is changed and effectiveness is recalculated. This maps out the cost effectiveness frontier in the way the we presented it to Marcus Peacock. The QAP, or protected acre is the inverse of damage or unwanted quality acres burned QAB. One is minus the other and this is evident in the objective function of the integer program. Max QAP = E_o – QAB. There are no "targets." This seems to be a land management planning construct as opposed to an initial attack construct.

Resource impacts and objectives.

Resource impacts are directly included and calculated through the weighting system. Unwanted and unplanned acres burned are evaluated differently depending upon the importance of their protection which is related to goals and objectives. This will do a much better job of addressing objectives than in previous versions because this model will better reflect the full range of market and non-market objectives, different planning units and agencies. In addition, the integrity of the formulation is sound.

Simulation of line production, ROS and fire intensity simulation

These are physical attributes of fire behavior that others can solve better. Andy and I have formulated the IP so as to make use of this information regardless of how it is generated. As currently formulated the IP will require input tables showing ROS, intensity and line production. We expected that line production would be user input and associated with a resource (a resource table) and that ROS would be simulated and that a sub-routine would then calculated perimeter and area by hour.

Should we exclude the escaped fire table from the model….

This was assigned to Howard Roose, but I should comment as how escaped fires are handled is an important part of any programming formulation. Andy and I have tried several approaches to formulation of the escaped fire and we would now suggest the following. An escaped fire is a fire that cannot be contained within the budget available for initial attack. It is therefore determined by the IP. By way of table input, the acres impacted by the escaped fire are input and available for use by the IP. The IP includes the effectiveness impact (or lack of) for acres not protected in the event of an escape. The cost of the escape is also user input and added to the final result of the run by a routine outside of the IP. This last part is necessary were we are maximizing QAP for a fixed budget. I will be glad to explain in more detail in our meeting.

17. How do we structure the process of assigning weights for management objectives…?

As you know I have some ideas about this would like to work on this problem. However, I would much prefer to work with a sub-group on this so that a weighting system design would properly reflect the concerns and operations of each of the agencies involved.

Can policies and procedures be forged for establishing weights at an interagency level?

I think so and would be delighted to work with an interagency team on this.

Our review of use cases, business rules etc. suggest that there are several that need to be clarified or reconsidered. This will be left to discussion at appropriate meetings.

NEXT STEPS

There is an enormous work that still needs to be addressed. Several that we view as priorities include: construction of an interagency framework and process for weighting, continued refinement of the formulation, generating an operational prototype—that runs on the computer, identifying a forest for a prototype application, generating written and oral materials that accurately document the model and the formulation, communicating with OMB and others.